

Application for Letters Patent

Title : MANUFACTURING METHOD OF A PHASE SHIFT MASK, METHOD OF FORMING A RESIST PATTERN AND MANUFACTURING METHOD OF A SEMICONDUCTOR DEVICE

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MANUFACTURING METHOD OF A PHASE SHIFT MASK, METHOD OF
FORMING A RESIST PATTERN AND MANUFACTURING METHOD OF A
SEMICONDUCTOR DEVICE

5 BACKGROUND OF THE INVENTION

10 Field of the Invention

 This invention relates to a manufacturing
method of a phase shift mask, a method of making a
resist pattern and a manufacturing method of a
semiconductor device, which are particularly suitable
for use when manufacturing a so-called Levenson phase
shift mask, making a resist pattern using a Levenson
phase shift and manufacturing a semiconductor device,
which makes a resist pattern by exposure using a
Levenson phase shift mask.

15 Description of Related Art

 Lithography process used when manufacturing a
semiconductor device, for example, is required to have
a high resolution beyond the resolution limit
determined by the wavelength of light used for exposure
along with progressive miniaturization of patterns.

 Recently, for the purpose of enabling
fabrication of micro patterns as small as or smaller
than the exposure wavelength, a technique has been
developed, which uses a high-resolution exposure photo
mask called phase shift mask, having a function of
modulating phase of transmission light and improving

the resolution utilizing interference of light. There are some kinds of such phase shift masks, e.g., Levenson-type masks in which light passing mask apertures corresponding to adjacent mask patterns is opposite in phase, and half-tone-type masks whose light shielding portions have a permeability and in which light through the shielding portion is opposite in phase from light passing through a mask aperture. Among those, Levenson phase shift mask have been used practically for manufacturing DRAM, high-speed LSI, and others, and they have been confirmed to be useful.

Levenson phase shift masks are generally classified into substrate excavation type masks made by excavating a quartz substrate as the mask substrate to ensure that light transmitting mask apertures corresponding to adjacent mask patterns is opposite in phase, and phase shifter-added type masks using a phase shifter formed on a quartz substrate.

As one of substrate excavation type Levenson phase shift mask structures, there is a dual trench structure. In the dual trench structure, both of the regions where light passing therethrough becomes opposite in phase, namely, 0° and 180° , are excavated because, by excavating both regions of 0° and 180° in phase, difference of contrast between transmission light having the phase of 0° and transmission light having the phase of 180° is small, and deviation upon

pattern transfer can be prevented. A specific example of the substrate excavation type Levenson phase shift mask structure is shown in Fig. 1. In Fig. 1, reference numeral 101 denotes a quartz substrate, 102 is a mask pattern, and 103 and 104 are excavated portions.

Figs. 2 and 3 show specific examples of the phase shifter-added type Levenson phase shift mask structure. Fig. 2 shows an overlying phase shifter-added type, and Fig. 3 shows an underlying phase shifter-added type. In Figs. 2 and 3, reference numeral 201 denotes a quartz substrate, 202 is a mask pattern, and 203 is the phase shifter.

In case of conducting exposure using the conventional Levenson phase shift mask, transmission light with the phase of 0° and transmission light with the phase of 180° are different from each other in variation in contrast caused by deviation of focal points (defocusing) that occurs upon exposure, and transfer displacement of the pattern occurs due to defocusing. Although a certain degree of defocusing may inevitably occur because of unevenness of the wafer surface for transferring the pattern to, various errors in the exposure device, manufacturing errors of the mask (for example, etching error produced upon excavation of the substrate), and so on, it is important to minimize pattern transfer displacement

within an expected defocusing region.

Heretofore, however, no concrete measure for minimizing transfer displacement of the pattern has been proposed.

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OBJECT AND SUMMARY OF THE INVENTION

10 It is therefore an object of the invention to provide a manufacturing method of a phase shift mask, capable of minimizing displacement of a transfer pattern while ensuring a lithography process tolerance when conducting exposure by using the phase shift mask, and thereby capable of improving the transfer
15 positional accuracy, and to provide a method of making a resist pattern by exposure using the phase shift mask, and a manufacturing method of a semiconductor device made by forming the resist pattern by exposure using the phase shift mask.

20 According to the invention, there is provided a manufacturing method of a phase shift mask, comprising:

seeking relationship of optical conditions of an exposure optical system used for exposure and a mask structure with displacement of a pattern to be transferred by exposure;

25 finding the optical conditions and the mask structure that can limit displacement of the pattern within a required range, taking manufacturing errors of

the mask into consideration;

examining the optical conditions and the mask structure, obtained, whether they ensure a required exposure tolerance and a required focal depth; and

5 executing fabrication of such a mask to obtain the mask structure when the result of the examination is acceptable.

According to the invention, there is further provided a method of making a resist pattern through exposure using phase shift mask, comprising:

10 seeking relationship of optical conditions of an exposure optical system used for exposure and a mask structure of the phase shift mask with displacement of a pattern to be transferred by exposure;

15 finding the optical conditions and the mask structure that can limit displacement of the pattern within a required range, taking manufacturing errors of the mask into consideration;

20 examining the optical conditions and the mask structure, obtained, whether they ensure a required exposure tolerance and a required focal depth; and

 when the result of the examination is acceptable, fixing the exposure optical system to the optical conditions selected, then actually
25 manufacturing the phase shift mask having the mask structure selected, and conducting exposure using the exposure optical system and the phase shift mask.

According to the invention, there is further provided a manufacturing method of a semiconductor device having a step of making a resist pattern through exposure using a phase shift mask;

5 seeking relationship of optical conditions of an exposure optical system used for exposure and a mask structure of the phase shift mask with displacement of a pattern to be transferred by exposure;

10 finding the optical conditions and the mask structure that can limit displacement of the pattern within a required range, taking manufacturing errors of the mask into consideration;

15 examining the optical conditions and the mask structure, obtained, whether they ensure a required exposure tolerance and a required focal depth; and

20 when the result of the examination is acceptable, fixing the exposure optical system to the optical conditions selected, then actually manufacturing the phase shift mask having the mask structure selected, and conducting exposure using the exposure optical system and the phase shift mask.

25 The process of determining optical conditions of an exposure optical system and a mask structure in the present invention is outlined in the flowchart of Fig. 4.

Representative optical conditions of the exposure optical system are numerical aperture (NA) and

partial coherence factor (σ). In exposure devices, in general, the value obtained by dividing the numerical aperture of an illumination optical system by the numerical aperture of the mask side of the projection optical system is called coherence. An intermediate value of such coherence (partial coherent illumination) between its value 0 (coherent illumination) and its value ∞ (incoherent illumination) is herein called the partial coherence factor.

The phase shift mask is typically a Levenson phase shift mask of any type of the substrate excavation type as shown in Fig. 1 or of the phase shifter-added type as shown in Figs. 2 and 3. The mask structure in the former substrate excavation type Levenson phase shift mask is determined regulated by the amount of excavation of the substrate, and displacement of the transfer pattern is minimized by optimizing the substrate excavation amount. The mask structure in the latter phase shifter-added Levenson phase shift mask is regulated by thickness of the phase shifter, and displacement of the transfer pattern is minimized by optimizing the thickness of the phase shifter.

In case of the simplest pattern like a uniform pattern in which a unit pattern is regularly arranged in equal intervals, determination of a pattern employed in Fig. 4 is determined by its design rule.

On the other hand, in case of a complicated, non-uniform pattern like logical LSI, etc., width and shape of the excavation, in case of a substrate excavation type Levenson phase shift mask, or width and shape of the phase shifter, in case of a phase shifter-added Levenson phase shift mask, also become complicated, and therefore, displacement of the transfer pattern and lithography process tolerance vary with the width and the shape. Therefore, it is necessary to optimize optical conditions and mask structure so as to prevent displacement over the entire pattern and to ensure lithography process tolerance. For this purpose, by grouping patterns that can be regarded the same pattern configuration, optimizing optical conditions and mask structure for each group and establishing optical conditions and mask structure satisfying the strictest conditions, optical conditions and mask structure can be optimized for patterns in each group.

According to the invention having the above-summarized structure, by seeking optical conditions and a mask structure capable of limiting displacement of a pattern within a required range, taking manufacturing errors of the mask into consideration, and repeating this procedure until desired exposure tolerance and focal depth are obtained with such optical conditions and the mask structure, it is possible to find optical conditions and a mask structure that are optical to

minimize pattern displacement while ensuring lithography process tolerance.

The above, and other, objects, features and advantage of the present invention will become readily apparent from the following detailed description thereof which is to be read in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a cross-sectional view that shows a substrate excavation type Levenson phase shift mask;

Fig. 2 is a cross-sectional view of a phase shifter-added Levenson phase shift mask;

Fig. 3 is a cross-sectional view of a phase shifter-added Levenson phase shift mask;

Fig. 4 is a flowchart that shows outline procedures for determining optical conditions of an exposure optical system and a mask structure;

Fig. 5 is a cross-sectional view that shows a substrate excavation type Levenson phase shift mask used in an embodiment of the invention;

Fig. 6 is a schematic diagram that shows a result of simulation executed with the embodiment of the invention;

Fig. 7 is a schematic diagram that shows a result of simulation executed with the embodiment of the invention;

Fig. 8 is a schematic diagram that shows an ED window after optimization of optical conditions of the exposure device and the mask structure in the embodiment of the invention; and

5 Figs. 9A through 9C are cross-sectional views showing a process of making a pattern in the embodiment of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

10 An embodiment of the invention is now explained below reference to the drawings.

This embodiment will be explained as determining an appropriate amount of excavation of a substrate and a resultant phase difference by simulation taking influences of the cross-sectional structure of the mask to exposure light into consideration in a substrate excavation type Levenson phase shift mask. Here is assumed a $0.26\mu\text{m}$ -pitch Line and Space pattern as the mask pattern.

20 Fig. 5 shows a structure of a substrate excavation type Levenson phase shift mask by simulation. In Fig. 5, reference numeral 1 denotes to a quartz substrate, 2 is a mask pattern made of a chromium (Cr) film, and 3 and 4 denote excavated portions. In this case, the excavated portion 4 is deeper than the excavated portion 3.

25 Fig. 6 is a result of simulation. In Fig. 6,

the abscissa represents amount of excavation of the deeper excavation 4 of Fig. 5, and the ordinate represents amount of displacement of the transfer pattern in case of the required focal depth being in the range from -0.3 to $0.3 \mu\text{m}$. Simulation was conducted on five different levels of the difference in excavation amount between the excavated portion 4 and the excavated portion 3. Fig. 6, however, represents the difference in excavation amount by the phase difference. When the phase difference is $\phi(^{\circ})$ wavelength of light used for exposure is λ (nm) and the refractive index of the glass portion is 1.51, the difference in excavation amount can be expressed as $(\phi/360 \times \lambda \div (1.51-1))$ (nm). Used as the exposure device was a KrF scanner with the numerical aperture NA-0.60 and partial coherence factor σ -0.53. In this case, $\lambda=248$.

Quartz substrate etching devices used in the $0.13 \mu\text{m}$ rule generation are expected to have etching errors of ± 4 nm in a 5-inch size mask surface. Therefore, in Fig. 6, displacement must be limited within the range of 8 nm of the abscissa. Referring to Fig 6, to satisfy this requirement, it is apparently sufficient to fix the amount of excavation of the deeper excavated portion 4 to 620 nm, remarking the curve for the phase difference of 169° , and in this case, the amount of excavation of the shallower

excavated portion 3 is $(169/360) \times 248 \div (1.51-1) \approx 230$ nm. It is known from this that, for minimizing the displacement of the transfer pattern, 620 nm as the amount of excavation of the excavated portion 4 and 390 nm as the amount of excavation of the excavated portion 3 are the best values.

Fig. 7 shows relationship between partial coherence factor σ and displacement within the required focal depth range. σ was tried in three different levels. It is known from Fig. 7 that displacement tends to decrease as σ decreases, and displacement is minimum when $\sigma=0.4$. Therefore, the partial coherence factor σ of the exposure optical system of the exposure device employed is fixed to 0.4.

Fig. 8 shows a window of luminous exposure tolerance and focal depth tolerance obtained when the mask structure of the substrate excavation type Levenson phase shift mask and optical conditions (NA, σ and so on) of the exposure device are optimized in the above-explained manner. It is known from Fig. 8 that exposure tolerance of 12% and focal depth of $0.95 \mu\text{m}$ are obtained and lithography process tolerance acceptable for mass production is obtained.

Figs. 9A through 9C show an example in which the lithography process according to the embodiment is applied to formation of a gate electrode of DRAM. That is, as shown in Fig. 9A, a conductive layer 52 as a

gate electrode material is formed on a silicon substrate 51 prepared by forming device isolating regions and a gate oxide film (not shown) on the surface of active region, and a resist 53 is coated thereon. Subsequently, the resist 53 undergoes exposure using a substrate excavation type Levenson phase shift mask having an optimized mask structure and an exposure device optimized in optical condition (NA, σ and others). There follows development to make out the resist patter 54 as shown in Fig. 9B.

Thereafter, by etching the conductive layer 52 by reactive ion etching (RIE) using the resist pattern 54 as the mask, the gate electrode 55 is obtained as shown in Fig. 9C.

As explained above, according to the embodiment, by exposure using the substrate excavation type Levenson phase shift mask optimized in mask structure, i.e. in amount of excavation of the excavated portion, and the exposure device optimized in optical conditions (NA, σ and others), displacement of the transfer pattern can be minimized to attain a high transfer positional accuracy while ensuring a sufficient lithography process tolerance.

Having described a specific preferred embodiment of the present invention with reference to the accompanying drawings, it is to be understood that the invention is not limited to that precise

embodiment, and that various changes and modifications may be effected therein by one skilled in the art without departing from the scope or the spirit of the invention as defined in the appended claims.

5 For example, although the embodiment has been explained as applying the invention to fabrication of a 0.26 μm pitch Line and Space pattern, design rule is not limited to this, and the invention is applicable to formation of a complicated pattern such as logical LSI pattern as well.

10 Further, although the foregoing embodiment uses the quartz substrate as the mask substrate, any appropriate one other than the quartz substrate may be used as the mask substrate.

15 As described above, according to the invention, displacement of the transfer pattern can be minimized to attain a high transfer positional accuracy while ensuring a sufficient lithography process tolerance when conducting exposure using a Levenson
20 phase shift mask. Additionally, by conducting exposure using a phase shift mask manufactured in that manner, a resist patter with a high positional accuracy can be made.